

LCA and ecodesign in the toy industry: case study of a teddy bear incorporating electric and electronic components

Ivan Muñoz · Cristina Gazulla · Alba Bala · Rita Puig ·
Pere Fullana

Received: 21 July 2008 / Accepted: 7 November 2008 / Published online: 4 December 2008
© Springer-Verlag 2008

Abstract

Background, aim, and scope A cradle-to-grave life cycle assessment (LCA) of a toy incorporating electric and electronic components is carried out following the ISO 14044 standard, with the purpose of identifying the environmental hotspots and suggesting ecodesign measures to the manufacturer.

Materials and methods The product under study is a teddy bear which sings songs and tells stories while moving its body, using conventional alkaline batteries as a source of energy. This toy is designed by a Spanish company, but manufactured entirely in China, from where it is exported to Europe, America, and Africa. The LCA study includes production of all components in China, maritime and road distribution, use phase, and end-of-life. Life cycle impact assessment is focused on five standard impact categories from the CML 2001 method.

Results The use phase is identified as potentially the most important life cycle stage, due to the impact of battery production. It is responsible for 50% to 64% of the overall life cycle impact, depending on the impact category. Toy production is also an important stage, with 28% to 34% of the total contribution. Maritime distribution also involves relevant contributions in some impact categories. Based on the results of the study, a set of ecodesign measures were suggested to the manufacturer, with most of them being judged as feasible, and applied in a new product.

Discussion Important data gaps were encountered during the study, especially concerning the use phase, due to lack of data on consumer behavior, and background inventory data on alkaline battery production. A sensitivity analysis applied to the use phase showed that the relative importance of this life cycle stage is strongly affected by the assumptions made in this work.

Conclusions The LCA study was found as a very helpful tool to define ecodesign measures for this product. Several measures suggested have been actually implemented by the manufacturer in a similar product.

Recommendations and perspectives This case study, together with others, will help in the long run to define general ecodesign measures for the toy sector in Catalonia.

Responsible editor: Walter Klöpffer

I. Muñoz
Department of Hydrogeology and Analytical Chemistry,
University of Almería,
Ctra. de Sacramento s/n, La Cañada de San Urbano,
E-04120 Almería, Spain

C. Gazulla · A. Bala · P. Fullana (✉)
Grup d'Investigació en Gestió Ambiental (GIGA),
Escola Superior de Comerç Internacional (ESCI),
Universitat Pompeu Fabra,
Pg. Pujades 1,
E-08003 Barcelona, Spain
e-mail: pere.fullana@admi.es

R. Puig
Escola Universitària d'Enginyeria Tècnica Industrial d'Igualada,
Universitat Politècnica de Catalunya (EUETII-UPC),
Plaça del Rei 1,
E-08700 Igualada, Spain

Keywords Batteries · Ecodesign · Electric and electronic components · Life cycle assessment · Teddy bear · Toys

1 Background, aim, and scope

Toy manufacturers are facing several challenges, such as concentration of sales in seasonal peaks (especially Christmas), an increased demand of toys with electronic components, and also consumer ecoawareness, among others (NPD

2007). However, in a country like Spain, where most of the toy industry is constituted by small and medium enterprises, the main concern is the strong pressure exerted by imports from eastern countries. China alone produces 70% of the world's toys, and most of the multinational companies from the USA, Taiwan, and Japan currently manufacture their products in that country (Herranz 2007). In such a globalized context, survival of the Spanish toy industry relies on quality, design, and innovation, key elements in the EU, which constitutes the main market for Spanish toys. For this reason, ecodesign constitutes an opportunity for this sector to strengthen its position, since ecodesigned products, besides being of good quality, provide the added value of a lower environmental impact. In addition, the EU's Integrated Product Policy, through regulatory and nonregulatory instruments, is progressively driving companies to include the environmental dimension in product design. Electric and electronic products, in particular, have been subject in recent years to a growing body of environmental legislation, such as the Waste Electric and Electronic Equipment Directive (WEEE; EU 2003a), and the Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (EU 2003b).

So far, almost nothing has been published on LCA and toys. Choi et al. (1997) carried out a case study dealing

with a toy train, although the environmental evaluation method cannot be called an LCA. So far, most of the literature dealing with environmental issues of toys is related to safety and risks from, e.g., exposure to chemicals like phthalates (Wilkinson and Lamb 1999). On the other hand, electric and electronic products have already been the focus of the LCA community for several years (Hischier et al. 2005; Scharnhorst 2008), although toys are not included in the range of products assessed.

In this work, we summarize the main findings of a case study carried out on a toy incorporating electric and electronic components. The paper describes the LCA application, as well as the ecodesign strategies adopted by the company as a result of the LCA study.

2 Product description

The product under study is called 'Winnie the Pooh Stories and Songs' (Fig. 1). It consists of a teddy bear placed on a plastic base, which moves its body and head while singing and telling short stories to the kids. It is around 30 cm high and weighs 0.73 kg or 1.05 kg including packaging. The toy works by means of three alkaline batteries of the LR14 (C) type, located at the bottom of the plastic base. Product design and development took place in the firm headquarters

Fig. 1 Product under study including packaging (left), and detail of internal parts: mechanical body (top right), and electric and electronic components (bottom right)



Table 1 Summary of main component weights

| Components | Weight (g) |
|--------------------------------|------------|
| Packaging | 313 |
| Figure | 137 |
| Base | 227 |
| Mechanical system | 125 |
| Electric and electronic system | 167 |
| LR6 batteries (3 units) | 72 |
| Total | 1,047 |

in Terrassa (Barcelona, Spain), whereas mass production takes place in the Chinese province of Fujian. We can distinguish six main sets of toy components (Table 1):

- Packaging, constituted by two big cardboard pieces and several minor elements aimed at fastening the toy.
- Figure, including the plush, red T-shirt, plastic eyes, and stuffing.
- Base, constituted of plastic housing and buttons.
- Mechanical system, composed of several internal parts (structural pieces, gears, etc.) acting as a joint skeleton.
- Electric and electronic system, including numerous elements like printed wiring boards, integrated circuits, cable, electric motors, speaker, switches, etc.
- Three LR6(AA) batteries supplied with the toy, aimed only at allowing potential customers to use the “try-me” function in the shop.

Concerning material composition, plastics, especially ABS and polyester, are the main constituents (52% of the total weight), followed by packaging cardboard (31%), ferrous metals (11%), and others (6%: copper, tin, ceramics, etc.).

3 LCA application

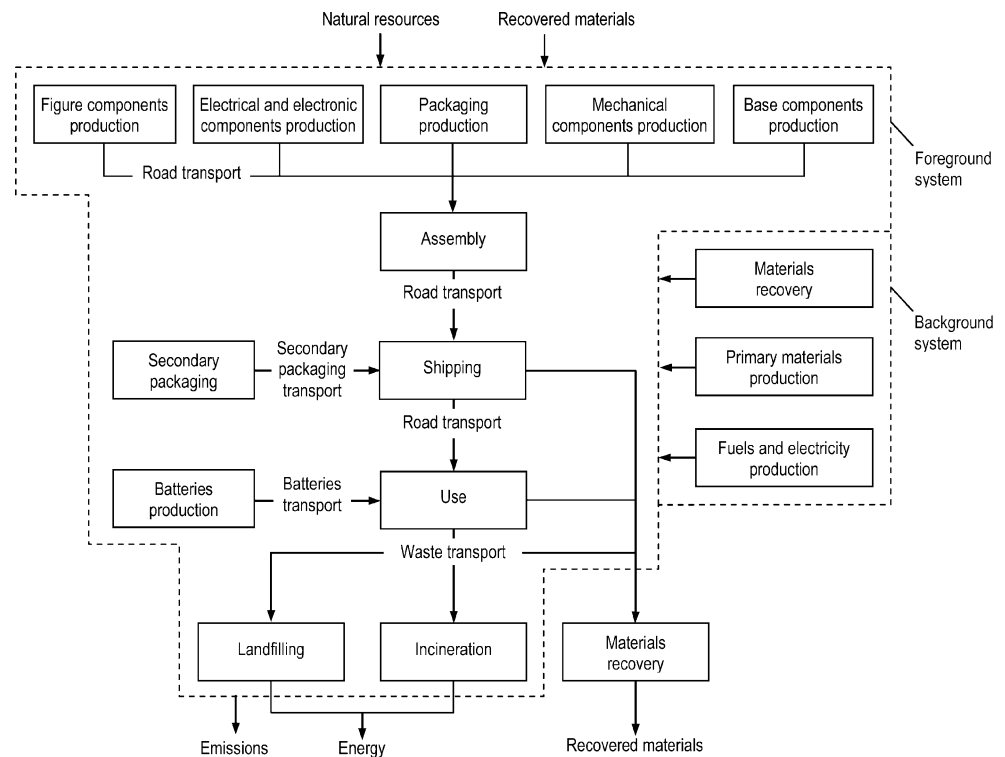
3.1 Goal

The goal of the LCA study is to identify the environmental hotspots, from cradle to grave, of the “Winnie the Pooh Stories and Songs” toy, in order to suggest ecodesign measures addressed to the manufacturer. It is not the goal of this study either to compare this product to other alternative products or to compare different end-of-life scenarios.

3.2 Product system and system boundaries

The system under study (Fig. 2) includes the complete product life cycle, namely, production of basic materials, transport and processing of the latter to obtain components, toy assembly, distribution from China to Europe, America, and Africa, production of alkaline batteries required in the use phase, and waste management. With regard to product components, all items are included, even those involving a very low contribution to the total product weight. On the

Fig. 2 Overview of the product system



other hand, infrastructure production was excluded from all processes, due to its expected lack of relevance in the case study. The employed background inventory data does not include infrastructure either.

3.3 Function and functional unit

Toys are used for entertaining purposes, in this case, by kids older than 18 months. Besides this main function, the end-of-life phase provides additional functions due to material and energy recovery in waste treatment processes. Since this is a noncomparative study, in principle, there is no need to expand the system in order to subtract the environmental burdens of these additional functions. Nevertheless, the latter was done in order to facilitate future comparisons with improved versions of the same toy. The chosen functional unit is a unit of “Winnie the Pooh Stories and Songs,” and a service lifetime of 2 years is assumed.

3.4 Allocation

Allocation affects three processes in the foreground system: landfilling, incineration, and open-loop recycling. On the other hand, allocation rules affecting background processes are not dealt with in this paper, since they are discussed in the corresponding database reports.

Both landfilling and incineration can produce electricity and heat as by-products. We dealt with these additional functions by means of system expansion and subtracting the corresponding environmental burdens from our system. Since the end-of-life phase takes place not only in Spain, but also in Italy, the UK, Switzerland, Germany, and other EU countries (60% of the toy units are sold in European countries other than Spain), coal was chosen as the reference marginal electricity production technology, according to Weidema et al. (1999). On the contrary, natural gas was selected as the heat source being replaced. Allocation of emissions and auxiliary materials in these waste treatment processes was carried out with the Ecoinvent models by Doka (2003), which allows the user to obtain inventories for products or waste fractions with specific compositions.

Concerning open-loop recycling, the “cutoff” method (Ekvall and Tillman 1997) was applied. By way of this method, each product is assigned only the burdens directly caused by that product. As a consequence, raw material production and waste disposal are allocated to those products actually linked to these processes, whereas recycling is allocated to the downstream product. This is the simplest allocation method according to Ekvall and Tillman (1997), since no data from outside the investigated product’s life cycle is required.

3.5 End-of-life scenario

Packaging materials and batteries benefit from consolidated separate collection and recycling channels in developed countries, whereas this is not so clear for toys. The latter are affected by Directive 2002/96/CE on WEEE, and member states have developed take-back and recycling schemes for different product categories, although none has been found to be exclusively focusing on toys (Savage et al. 2006), so it has not been possible to find wide-ranging statistics on collection and recycling for this category of products. In general, it seems likely, in countries where toys are being separately collected, that this is done together with other electronic equipment from households. In Spain, data for 2006 have shown that only a negligible fraction of separate collection and recycling was achieved for toys (ECOTIC 2006).

In the end, since there is virtually no established waste collection pathway for toys in most countries, and also because the goal of the study was not to compare end-of-life scenarios, we decided to consider no separate collection, but comingled collection with other household waste sent to disposal. The shares of landfilling and incineration were determined on the basis of European statistics (Eurostat 2006) and weighed by the amount of toy units sold in each country, resulting in, respectively, 77% landfilling and 23% incineration. For Latin America and Africa, landfilling was assumed to be the only waste treatment method, since no data at all was found on waste management in the corresponding countries.

With regard to the other elements in the product system, namely, batteries and packaging, the recycling rate has been defined for each fraction according to European statistics (EC 2004; BIO Intelligence Service 2003), while for Latin America and Africa, only landfilling was considered.

3.6 Data sources and main hypotheses

Due to the product’s complexity, a detailed description of all the used data cannot be made here. Instead, a summary of the main data sources and gaps is provided. The background system was modeled with the PE International LCA databases, using for this purpose the GaBi 4.2 software (LBP and PE 2007). The toy manufacturer supplied a bill of materials, along with a complete set of unitary components, more than 100 in total. The manufacturer also supplied information about the product logistics and energy efficiency in terms of energy use. Components production and assembly takes place in the Fujian province, whereas it is shipped from the Xiamen port to the importing countries. According to the manufacturer, 93% is shipped to Europe (61% to Spain alone), 6% to Latin America, and 1% to Africa.

Road transport and energy consumption taking place in China was modeled according to the situation in that country: a truck transport model was created, using data from Fritsche and Schmidt (2006), whereas thermal energy consumption was modeled assuming coal, since the latter is the main energy source in China (International Energy Agency 2005). As for electricity, the Chinese production profile was used (International Energy Agency 2005).

At the time this study was performed, the only LCA database available including datasets for electric and electronic components was the one by PE International. However, this database was far from being complete enough in order to properly model all the components involved, and it was necessary to complement it with a few educated assumptions made with the help of the developers of this database (Herrmann 2006). For example, the database includes only surface-mount devices (SMD), whereas the toy is based on through-hole devices.

One of the most important data gaps encountered is the lack of background inventory data and published LCA studies on conventional batteries. It is surprising that only a single LCA study was found for such a common product in our day-to-day life (Parsons 2007). Due to the lack of data when our study was carried out, the production of alkaline batteries was modeled using a rough material composition (Table 2) obtained from a Spanish battery recycling company (Ribera 2006): water (6–9%), carbon (3–5.5%), steel (17–23%), zinc (14–18%), manganese dioxide (34–42%), potassium hydroxide (3–6.8%), plastics and paper (2.5–4.3%), impurities (<1%). Battery production was modeled as production of these raw materials in the corresponding amounts per battery. The assumption was made to only consider single-use batteries, since it was assumed that these would be the most widely employed type by the average user. Concerning the number of batteries needed during the use phase, this is unknown to the manufacturer and had to be set as a hypothetical scenario: a 2-year useful life and a use rate of 1 h/week were chosen in this respect. This results in a demand of 39 LR14(C) alkaline batteries, according to the toy's energy

efficiency, plus the initial LR6(AA) batteries used in the “try-me” mode.

3.7 Life Cycle Impact Assessment methodology

Life Cycle Impact Assessment (LCIA) has been applied at the midpoint level (Udo de Haes et al. 1999). Only the mandatory features according to ISO 14044 (ISO 2006) have been applied, namely, impact category selection, classification, and characterization. The assessment has focused only on five impact categories typically used in most LCA studies: abiotic depletion potential (ADP), acidification potential (AP), global warming potential (GWP), eutrophication potential (EP), and photochemical oxidants formation potential (POFP). The characterization models used are those by the CML at Leiden University (Guinée et al. 2002).

The following impact categories were not included for the following reasons:

- Ozone layer depletion potential (ODP): use of ozone depleting gases such as CFCs and HCFCs is severely restricted in many countries by an international moratorium; detailed information on the use of these substances in the specific processes that are part of the present case study are lacking.
- Human and eco-toxicity potentials (HTP and ETPs): these impact categories would, in fact, be relevant in the analyzed case study. Unfortunately, however, the available LCI data were not deemed reliable enough for the purposes of estimating toxicity potentials. Moreover, no universal consensus has yet been reached as to which characterization model should be employed, and the different available methods often lead to diverging results. Using different methods was not found feasible because of the lack of LCI data.
- Soil use impact: the employed LCI database does not contain information regarding soil use; moreover, no universally accepted characterization model exists. In any case, it can be assumed for the analyzed case study that this category should not be particularly relevant.

3.8 LCIA results

Figure 3 shows the absolute LCIA scores and the relative weight of different processes and life cycle stages for the toy under study. In this figure, the production phase is split into five sets of components: base, figure, electric and electronic system, mechanical system, and packaging. All together, the production phase is responsible for 24% to 40% of the total life cycle impact, depending on the impact category. In this life cycle stage, all groups of components are relevant, especially the figure (7–12%), base (4–12%),

Table 2 Approximate composition of alkaline batteries

| Alkaline battery materials | Composition (%) |
|----------------------------|-----------------|
| Water | 6–9 |
| Carbon | 3–5.5 |
| Steel | 17–23 |
| Zinc | 14–18 |
| Manganese dioxide | 34–42 |
| Potassium hydroxide | 3–6.8 |
| Plastics and paper | 2.5–4.3 |
| Impurities | <1 |

Source: Ribera 2006

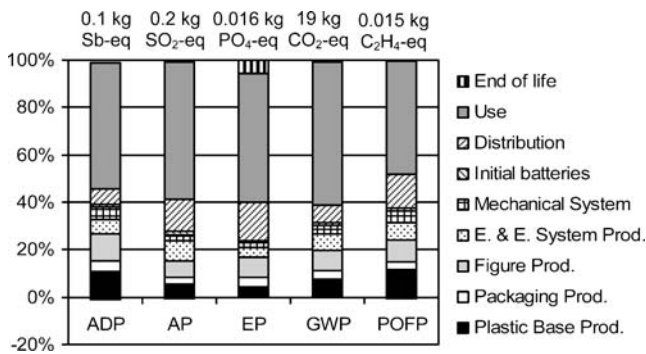


Fig. 3 Environmental profile of the toy under study

and electric and electronic system (4–9%). Due to the complexity of the electric and electronic system, a more detailed analysis of the results is shown in Fig. 4. It can thus be seen that five components—out of more than fifty—are collectively responsible for around 90% of the total impact of this subsystem. The most important individual elements are the electric motors (50% of total EP) and the PWBs (47% of total ADP).

Concerning the gate-to-grave life cycle stages, Fig. 3 shows that both distribution and use are important, especially the latter. With regard to distribution, it causes 14% of GWP and 16% of EP, and it is mostly related to maritime transport from China to the importing countries. The weighed transport distance from China to these countries was estimated to be 16,500 km, but this distance was doubled in the inventory, since the containers are sent back to China empty (this piece of information was directly provided by the manufacturer).

Toy disposal appears to be the least important life cycle stage. Its most important contribution to the impact categories only amounting to 6% in the case of EP. Only landfilling and incineration are taken into account in the end-of-life phase, since, according to the “cutoff” allocation method, the recycling process is allocated to the downstream product in the cascade.

The use phase appears clearly as the most important one in the toy’s life cycle, being responsible for 48% to 64% of the total contribution, depending on the impact category. The environmental burdens of the use phase are related to battery production and disposal, production being the most important stage according to our results. Nevertheless, as discussed in Section 2.6, the impact of the use phase is subject to a very high uncertainty due to: (1) lack of data on consumer behavior, i.e., product useful life and use rate, and (2) poor data used to model battery production. Our consumer behavior scenario can be considered optimistic (intensive use and relatively long product life); additionally, the impact of battery production is very likely to be underestimated. In order to check the implications of our usage rate hypothesis, a sensitivity analysis was carried out,

in which a more pessimistic scenario was considered: after exhausting the first set of LR14(C) batteries, the consumer would not replace them, and the toy would just stay in the shelf as a decorative element. In Table 3, it can be seen that this pessimistic scenario involves drastic changes in the importance of the use phase, as its contribution falls from 48–59% to less than 2% in all impact categories. As a consequence, taking into account a pessimistic use rate, production and distribution become the most important life cycle stages.

ADP and AP indicators exhibit slightly negative values in the pessimistic scenario. This is due to the avoided impact associated with the recycling of the LR6(AA) batteries initially supplied with the toy, as well as, to a lesser degree, of its packaging. It should be noted that, while the demonstration batteries were allocated to the toy’s production phase, the subsequent LR14(C) batteries (which are only present in the optimistic scenario) were allocated to the use phase.

4 Ecodesign

4.1 Proposed measures

While carrying out the LCA study, as well as after the results were obtained, several ideas arose on how to improve “Winnie the Pooh Stories and Songs” from an environmental point of view. These suggestions were presented to the company representatives and appraised, taking into account technical feasibility, environmental and economic relevance, and consumer acceptance, leading to a final priority judgment, ranking from unfeasible to applicable in the short-term. Table 4 summarizes the proposed ecodesign measures and the results of the appraisal. As can be seen in the table, out of 11 proposed measures, only two were rejected on the basis of their unfeasibility, while five of them were judged as applicable in the short term.

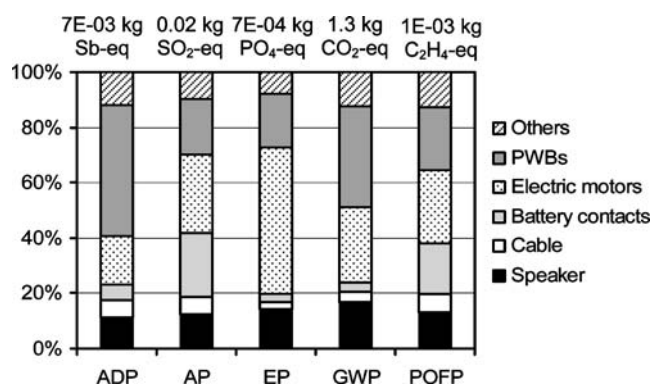


Fig. 4 Environmental profile of electric and electronic components production

Table 3 Contribution of the use phase to the total cradle to grave impacts considering different consumer use patterns

| Use scenario | ADP (%) | AP (%) | EP (%) | GWP (%) | PFOP (%) |
|--|---------|--------|--------|---------|----------|
| Optimistic: 1 h/week, during 2 years (39 batteries in total) | 54 | 59 | 54 | 60 | 48 |
| Pessimistic: first set of exhausted batteries is not replaced (3 batteries in total) | −0.3 | −0.17 | 1.2 | 1.8 | 0.2 |

4.2 Application of measures

So far, “Winnie the Pooh Stories and Songs” has not been subject by the manufacturer to any of the proposed changes. Nevertheless, it has been done to some extent to a similar product launched in the following Christmas campaign: “Mickey Sings and Dances” (IMC Toys 2007). This new toy consists basically of the same concept, a standing plush capable of talking/singing while moving its body. The improvements put into practice by the manufacturer are the following (numbers refer to Table 4):

1. Through hole technology has been discarded. All electronic components are now SMD, of smaller size, and demand less PWB area.
4. Plush stuffing is now made of recycled plastic fibers instead of virgin fibers.
6. The use of rechargeable batteries is recommended in the instructions, along with other suggestions concerning separate collection and recycling of the different items (batteries, packaging, toy).
7. Energy demand of the toy while being used has been decreased around 20%. This involves longer life for

batteries and allows for the use of smaller LR6(AA) units.

8. Some minor elements in the packaging have been removed (adhesive tape, strapping wire).
10. Instead of shifting from polypropylene to ABS, battery adaptors have been simply removed, since the “try-me” and normal use modes are now carried out with the same battery type (LR6(AA)).

Additionally, the amount of plastic used has been reduced by 30% due to the removal of the base. Toy controls are now placed in a smaller console located at the right side of the figure.

It is the purpose of the manufacturer to communicate these improvements to the consumer, by placing a message on the packaging, but this cannot be done without the permission of the licenser, who keeps the rights on this and other issues related to image and communication.

All these measures contribute to reducing the life cycle impacts of the toy, although this has not been proved by means of a comparative LCA of “Winnie the Pooh Stories and Songs” and “Mickey Sings and Dances.” Although they are different toys, they can be considered in practice as

Table 4 Ecodesign measures and appraisal

| No. | Measure | Technical practicability | Economic relevance ^a | Environmental relevance ^a | Consumer acceptance ^a | Priority |
|-----|---|--------------------------|---------------------------------|--------------------------------------|----------------------------------|-------------|
| 1 | Shifting from through-hole to SMD electronic components | Yes | 2 | 1 | 2 | Medium term |
| 2 | Changing packaging shape to minimize losses at the cutting step | Yes | 2 | 1 | 2 | Medium term |
| 3 | Substitute synthetic polyester by organic cotton in plush and T-shirt | No | | | | Rejected |
| 4 | Use recycled instead of virgin fibers in plush stuffing | Yes | 1 | 1 | 2 | Long term |
| 5 | Use recycled plastics in hidden components | Yes | 2 | 1 | 2 | Medium term |
| 6 | Use rechargeable batteries | Yes | 3 | 2 | 2 | Short term |
| 7 | Reduce energy demand in use mode | Yes | 3 | 3 | 3 | Short term |
| 8 | Reduce the number of different materials in packaging | Yes | 3 | 1 | 2 | Short term |
| 9 | Avoid incompatible plastics during recycling in packaging | Yes | 3 | 1 | 2 | Short term |
| 10 | Shift from polypropylene to ABS in battery adaptor | Yes | 3 | 1 | 2 | Short term |
| 11 | Marking of packaging plastics with their identification symbols | No | | | | Rejected |

^a Ranked from 0 to 3, with three representing the highest relevance

functionally equivalent and therefore could be easily compared in an LCA study using a physical functional unit. Taking into account the environmental profile of the original toy, however, we can discuss in a qualitative way the impact of these measures on the new product's life cycle:

- The distribution phase should remain essentially unchanged, if the same distribution scheme is assumed.
- End-of-life is the least important life cycle stage in all the considered impact categories; therefore, no significant changes are to be expected.
- In the production phase, the new toy appears as environmentally preferable, due to material savings in the base, electronic components, and use of recycled stuffing.
- In the use phase, the highest potential improvement would be seen, due to increased energy efficiency leading to lower battery demand. However, the magnitude of the overall improvement would again depend on the consumer use patterns, which were identified as one of the main uncertainties in the study.

Last but not the least, even though the recycling option was left out of the analysis presented here, it clearly still bears relevance from the point of view of the ecodesign recommendations, with the purpose of improving the environmental performance of the toy. In particular, the toy's recyclability must be judged, taking into account the current technologies used for WEEE recycling. During this project, a modern WEEE recycling plant was visited in Barcelona¹, in order to find out how our toy would be treated by a recycler. The conventional WEEE recycling process can basically be described as consisting of two steps: in the first step, hazardous components as well as valuable nonmetallic materials are dismantled by hand. In the second step, the remaining parts are processed by means of crushing, shredding, and mechanical sorting of the metallic fraction, while the refuse fraction (including all nondismantled plastics) is sent to disposal. By this process, the metallic fraction of the toy would be easily recycled, but plastics should be dismantled by hand, resulting in a labor-demanding and therefore expensive operation, which would not take place in this plant unless it was subsidized by the take-back scheme. As a consequence, the fate of plastics in toys seems to be disposal, unless they can be easily dismantled or some technology is developed in order to easily separate the shredded fractions.

5 Conclusions and perspectives

An LCA study was carried out on a toy, namely, a teddy bear incorporating electric and electronic components. The

study covered the complete cradle-to-grave cycle, and its primary goal was to identify the main environmental hotspots, in order to suggest ecodesign measures to the manufacturer. The most important life cycle stage was found to be the use phase, due to production of alkaline batteries. This stage is responsible for 50% to 64% of the total life cycle impacts, although these figures are subject to a remarkable uncertainty, not only due to lack of data on consumer behavior, but also to lack of background inventory data on battery production. The production phase is second in order of importance, and distribution of the toy from China to the importing countries is third.

From the LCA results themselves, but also from the detailed product analysis that an LCA requires, several ecodesign measures were proposed to the manufacturer, most of which were accepted, and some of them have been already applied to a similar toy.

Acknowledgement The work presented here was entirely carried out while Ivan Muñoz was working at Grup d'Investigació en Gestió Ambiental (GiGa), Escola Superior de Comerç Internacional, Universitat Pompeu Fabra. This author gratefully acknowledges the support he received there. The authors also acknowledge the Centre for Enterprise Innovation and Development (CIDEM), the Department of Environment and Housing of the Government of Catalonia (Spain) and IMC Toys for their financial support under the ECOJOGUINA project (this LCA is one of the four case studies performed within the project), and Josep Matarín from IMC Toys for his valuable collaboration. ESCI was awarded the 2008 Environment Prize by the Government of Catalonia (Premi Medi Ambient de la Generalitat de Catalunya) for the ECOJOGUINA project under the category Universities.

References

- Bio Intelligence Service (2003) Impact Assessment on Selected Policy Options for Revision of the Battery Directive. Final Report. Prepared for the European Commission, Directorate General Environment
- Choi ACK, Kaebernick H, Lai WH (1997) Manufacturing processes modelling for environmental impact assessment. *J Mater Process Tech* 70(1–3):231–238
- Doka G (2003) Life Cycle Inventories of Waste Treatment Services. Final report ecoinvent 2000 No. 13, EMPA St. Gallen, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland
- EC (2004) Packaging and packaging waste. http://ec.europa.eu/environment/waste/packaging_index.htm
- ECOTIC (2006) Personal communication—Fundación ECOTIC. Barcelona. www.ecotic.es
- Ekvall T, Tillman AM (1997) Open-loop recycling: criteria for allocation procedures. *Int J Life Cycle Assess* 2(3):155–162
- EU (2003a) Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electric and electronic equipment (WEEE). *Official Journal L* 037, 13/02/2003 P. 0024 – 0039
- EU (2003b) Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electric and electronic equipment. *Official Journal L* 037, 13/02/2003 P. 0019 – 0023.

¹ Viuda de Lauro Clariana, S.L. www.viudaclariana.com

- Eurostat (2006) Municipal waste treatment, by type of treatment method. Environment and Energy Statistics
- Fritsche U, Schmidt K (2006) Global Emission Model of Integrated Systems. Manual. Öko-institut e.V., Darmstadt, Germany. www.oeko.de/service/gemis/en/
- Guinée J (ed), Gorée M, Heijungs R, Huppes G, Kleijn R, König A, van Oers L, Wegener A, Suh S, Udo de Haes E, Bruijn H, Duin R, Huijbregts M, Lindeijer E, Roorda A, van der Ben B, Weidema B (2002) Life Cycle Assessment. An operational guide to the ISO standards. Volume 1, 2, 3. Centre of Environmental Science—Leiden University (CML), The Netherlands
- Herranz J (2007) Informe del Sector Juguetes en 2006. Subdirección general de COMEX de Productos Industriales. Ministerio de Industria, Comercio y Turismo
- Herrmann C (2006) Personal Communication. Project Manager, PE Europe GmbH. Leinfelden-Echterdingen, Germany
- Hischier R, Wager P, Gaughhofer J (2005) Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electric and electronic equipment (WEEE). *Environ Impact Assess* 25(5):525–539
- IMC Toys (2007) Professional Catalogue, Mickey Mouse Club House. <http://www.imctoys.com/AreaProfesional/catalogo.aspx?id=IMC&x=0>
- International Energy Agency (2005) Electricity/Heat in China, People's Republic of, in 2005. www.iea.org
- ISO (2006) ISO 14044: Environmental management—Life cycle assessment—Requirements and guidelines. Geneva, Switzerland
- LBP, PE (2007) GaBi 4 Software-System and Databases for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen. www.gabi-software.com
- NPD (2007) Toy Markets in the World. Prepared for the International Council of Toy Industries by NPD. www.toy-icti.org/
- Parsons D (2007) The environmental impact of disposable versus rechargeable batteries for consumer use. *Int J Life Cycle Assess* 12(3):197–203
- Ribera J (2006) Personal Communication. Head of laboratory, Pilagest S.L. Pont de Vilomara i Rocafort, Bages, Barcelona, Spain. www.pilagest.es
- Savage M, Ogilvie S, Slezak J, Artim E, Lindblom J, Delgado L (2006) Implementation of Waste Electric and Electronic Equipment Directive in EU 25. Technical Report Series, Institute for Prospective Technological Studies, European Commission
- Scharnhorst W (2008) Life cycle assessment in the telecommunication industry: a review. *Int J Life Cycle Assess* 13(1):75–86
- Udo de Haes HA, Jolliet O, Finnveden G, Hauschild M, Krewitt W, Muller-Wenk R (1999) Best available practice regarding impact categories and category indicators in life cycle impact assessment background. Document for the Second Working Group on Life Cycle Impact Assessment of SETAC-Europe (WIA 2). *Int J Life Cycle Assess* 4(2):66–74
- Weidema BP, Frees N, Nielsen AM (1999) Marginal production technologies for life cycle inventories. *Int J Life Cycle Assess* 4(1):48–56
- Wilkinson CF, Lamb JC (1999) The potential health effects of phthalate esters in children's toys: a review and risk assessment. *Regul Toxicol Pharm* 30(2):140–155